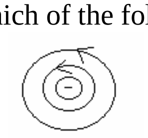
SPH4U1 - Electric and Gravitational Fields

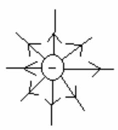
Multiple Choice (1 mark each)
Identify the letter of the choice that best completes the statement or answers the question.

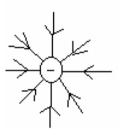
____ 1. The electrostatic force between two point charges is 3.4×10^{-7} N. If the distance between the charges is tripled but the size of the charges remains the same, the force between them will be

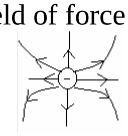
a) 3.1×10^{-6} N
b) 3.8×10^{8} N
c) 2.6×10^{7} N
d) 3.8×10^{-8} N
e) 1.1×10^{-7} N

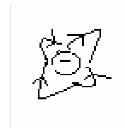
____ 2. Which of the following diagrams represents the field of force around a negative point charge?

a) 

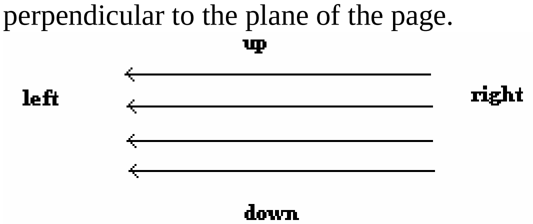
b) 

c) 

d) 

e) 

____ 3. The direction of a magnetic field $\vec{B}$ is from right to left as shown below. A proton travels into and perpendicular to the plane of the page.



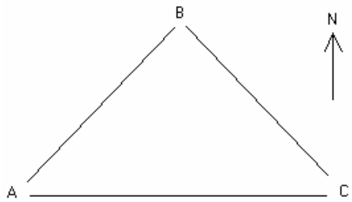
The direction of the magnetic force acting on the proton is
a) down
b) up
c) right
d) left
e) directly out of the page and perpendicular to the paper

Short Answer

1. State two ways that Coulomb's law differs from Newton's law of universal gravitation. **(2 marks)**
2. Why does the magnetic force have no effect on the magnitude of velocity of a charged particle? **(2 marks)**

Problem

1. Three identical point charges A, B, and C are located as shown on the diagram. A exerts force ***F*** on B. An equal force ***F*** is exerted by C on B ($\angle ABC = 90°$). What is the net force on B (in terms of ***F***)? **(3 marks)**

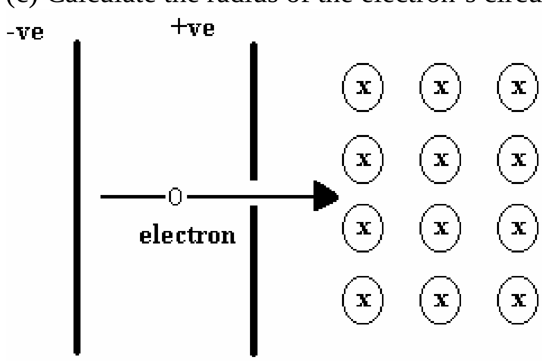


2. Two charges, one of charge $+2.5 \times 10^{-5}$ C and the other of charge -3.7×10^{-7} C, are 25.0 cm apart. The positive charge is to the left of the negative charge.
   (a) Draw a diagram showing the point charges and between them label a point Y that is 10.0 cm away from the negative charge, on the line connecting the charges. (Field lines do not need to be drawn.) **(2 marks)**
   (b) Calculate the electric field at point Y. **(5 marks)**

3. In a Millikan-type experiment, two horizontal parallel plates are 1.0 cm apart. A sphere of mass 2.2×10^{-13} kg remains stationary when the potential difference between the plates is 350 V with the upper plate negative.
   (a) Is the sphere positively or negatively charged? Explain. **(2 marks)**
   (b) Calculate the magnitude of charge on the sphere. **(4 marks)**

4. Two spheres are located 0.50 m from one another. Sphere A with a charge of -2.7×10^{-4} C, is fixed in position, but sphere B with a charge of -5.6×10^{-5} C is free to move. Spheres A and B each have a mass of 1.3×10^{-2} kg. How fast is sphere B moving when it reaches a distance of 0.95 m from sphere A? (Assume all distances are centre-to-centre.) **(4 marks)**

5. An electron accelerates from rest through an electric field and into a magnetic field as shown in the diagram below. The plates have a potential difference of 25 V, and the magnetic field has a magnitude of 0.50 T. (Remember: $m_e = 9.1 \times 10^{-31}$ kg and $e = 1.6 \times 10^{-19}$ C.)
   (a) Calculate the initial speed of the electron upon entering the magnetic field. **(4 marks)**
   (b) Calculate the magnitude and direction of the magnetic force on the electron. **(4 marks)**
   (c) Calculate the radius of the electron's circular path. **(3 marks)**



6. Calculate the magnitude of the force per unit length (in N/m) between two parallel straight conductors 5.0 cm apart, each carrying a current of 4.0 A. **(5 marks)**

SPH4U1 - Electric and Gravitational Fields
Answer Section

MULTIPLE CHOICE

1.	ANS: D	REF: C	OBJ: 7.2	LOC: EG1.03
2.	ANS: C	REF: K/U	OBJ: 7.3	LOC: EG1.04
3.	ANS: B	REF: K/U	OBJ: 8.2	LOC: EG1.08

SHORT ANSWER

1. ANS:
   - The electric force can attract or repel, depending on the charges involved, whereas the gravitational force can only attract.
   - The universal constant $G = 6.67 \times 10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2$ is very small, meaning that in many cases the gravitational force can be ignored unless at least one of the masses is very large. On the other hand, Coulomb's constant $k = 9.0 \times 10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2$ is very large, implying that even small charges can result in noticeable forces.

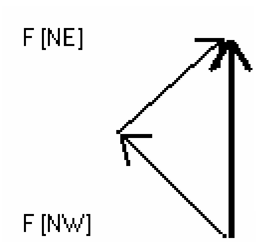
   REF: K/U OBJ: 7.2 LOC: EG1.02

2. ANS:
   - The force is perpendicular to the velocity.
   - No component of the force acts in the direction of motion of the charged particle.
   - The magnetic field cannot change the energy of the particle and, therefore, the magnitude of the velocity remains unchanged.

   REF: K/U OBJ: 8.2 LOC: EG1.08

PROBLEM

1. ANS:



$\sqrt{2}\,F$ [N]

$$(F_{net})^2 = F^2 + F^2$$

$$(F_{net})^2 = 2F^2$$

$$F_{net} = \sqrt{2}\,F$$

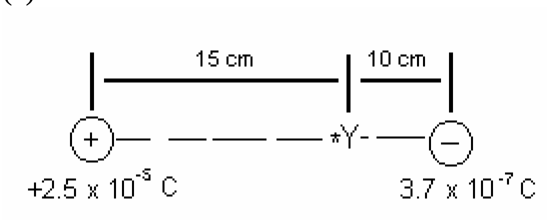
$$F_{net} = \sqrt{2}\,F\ [\text{N}]$$

The net force on B is $\sqrt{2}F$ [N].

REF: C OBJ: 7.2 LOC: EG1.06

2. ANS:

(a)



(b)

$q_1 = 2.5 \times 10^{-5}$ C
$q_2 = -3.7 \times 10^{-7}$ C
$r_1 = 25.0$ cm
$r_2 = 10.0$ cm
$\varepsilon = ?$

$r_1 = 25.0 \text{ cm} - 10.0 \text{ cm} = 15.0 \text{ cm} = 0.15 \text{ m}$

$$\varepsilon_1 = \frac{kq_1}{r_1^2}$$

$$= \frac{\left(9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2\right)\left(2.5 \times 10^{-5}\text{ C}\right)}{(0.15 \text{ m})^2}$$

$$\varepsilon_1 = 1.00 \times 10^7 \text{ N/C}$$

$$\vec{\varepsilon}_1 = 1.00 \times 10^7 \text{ N/C [right]}$$

$$\varepsilon_2 = \frac{kq_2}{r_2^2}$$

$$= \frac{\left(9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2\right)\left(3.7 \times 10^{-7}\text{ C}\right)}{(0.10 \text{ m})^2}$$

$$\varepsilon_2 = 3.33 \times 10^5 \text{ N/C}$$

$$\vec{\varepsilon}_2 = 3.33 \times 10^5 \text{ N/C [right]}$$

$$\Sigma\vec{\varepsilon} = \vec{\varepsilon}_1 + \vec{\varepsilon}_2 = 1.0 \times 10^7 \text{ N/C [right]}$$

The net electric field is 1.0×10^{7} N/C [right].

REF: C OBJ: 7.3 LOC: EG1.06

3. ANS:
r = 1.0 cm = 0.010 m
$m = 2.2 \times 10^{-13}$ kg
ΔV = 350 V
q = ?
N = ?

(a)
The electric force must be up to balance the downward force of gravity. The upper plate is negative and the bottom plate is positive. The sphere must be positively charged to be repelled by the bottom plate and attracted to the upper plate.

(b)
$F_E = F_g$ and $\varepsilon = \frac{\Delta V}{r}$

$q\varepsilon = mg$

Therefore, $\frac{q\Delta V}{r} = mg$

$$q = \frac{mgr}{\Delta V}$$

$$= \frac{(2.2 \times 10^{-13}\ \text{kg})(9.8\ \text{m/s}^2)(0.010\ \text{m})}{350\ V}$$

$$q = 6.2 \times 10^{-17}\ \text{C}$$

The magnitude of charge on the sphere is 6.2×10^{-17} C.

REF: C OBJ: 7.5 LOC: EG1.06

4. ANS:
$m = 1.3 \times 10^{-2}$ kg
$q_A = -2.7 \times 10^{-4}$ C
$q_B = -5.6 \times 10^{-5}$ C
r_1 = 0.50 m
r_2 = 0.95 m
v_1 = 0
v_2 = ?

$$E_{K2} = \Delta E_K = -\Delta E_E$$

$$E_{K2} = -\left(\frac{k_{q_1 q_2}}{r_2} - \frac{k_{q_1 q_2}}{r_1}\right)$$

$$= -\left[\frac{\left(9.0\times10^{9}\ \mathrm{N\cdot m^2/c^2}\right)\left(-5.6\times10^{-5}\ \mathrm{c}\right)\left(-2.7\times10^{-4}\ \mathrm{c}\right)}{0.95\ \mathrm{m}} - \frac{\left(9.0\times10^{9}\ \mathrm{N\cdot m^2/c^2}\right)\left(-5.6\times10^{-5}\ \mathrm{c}\right)\left(-2.7\times10^{-4}\ \mathrm{c}\right)}{0.50\ \mathrm{m}}\right]$$

$$E_{K2} = 1.29\times10^{2}\ \mathrm{J}$$

$$V_2 = \sqrt{\frac{2E_{K2}}{m}}$$

$$= \sqrt{\frac{2(1.29\times10^{2}\ \mathrm{J})}{1.3\times10^{-2}\ \mathrm{kg}}}$$

$$V_2 = 1.4\times10^{2}\ \mathrm{m/s}$$

Sphere B will be moving with a speed of 1.4×10^2 m/s.

REF: C   OBJ: 7.6   LOC: EG1.06

5. ANS:
V = 25 V
B = 0.50 T = 0.50 kg/C·s
$m_e = 9.1 \times 10^{-31}$ kg
v = ?
F_M = ?
r = ?

(a)

$$-\Delta E_E = \Delta E_K$$

$$qV = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2qV}{m}}$$

$$= \sqrt{\frac{2(1.6 \times 10^{-19}\ \text{C})(25\ \text{V})}{9.1 \times 10^{-31}\ \text{kg}}}$$

$$= 2.96 \times 10^6\ \text{m/s}$$

$$v = 3.0 \times 10^6\ \text{m/s}$$

The initial speed of the electron upon entering the magnetic field is 3.0×10^6 m/s.

(b)

$$F_M = qvB|\sin\theta|$$

$$= (1.6 \times 10^{-19}\ \text{C})(2.96 \times 10^6\ \text{m/s})(0.50\ \text{kg/C}\cdot\text{s})|\sin 90°|$$

$$F_M = 2.4 \times 10^{-13}\ \text{N}$$

The right-hand rule tells us the direction of the force is toward the bottom of the page.
The magnitude of the force is 2.4×10^{-13} N [toward the bottom of the page].

(c)

$$F_M = F_c$$

$$qvB = \frac{mv^2}{r} \qquad \text{since } \sin 90° = 1$$

$$r = \frac{mv}{Bq}$$

$$= \frac{(9.1 \times 10^{-31}\ \text{kg})(2.96 \times 10^6\ \text{m/s})}{(0.50\ \text{T})(1.6 \times 10^{-19}\ \text{C})}$$

$$r = 3.4 \times 10^{-5}\ \text{m}$$

The radius of the circular path is 3.4×10^{-5} m.

REF: C OBJ: 8.2 LOC: EG1.08

6. ANS:
d = 5.0 cm = 0.050 m
I_1 = 4.0 A
I_2 = 4.0 A
F = ?

$$\frac{F_2}{l} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

$$= \frac{\mu_0 I_1 I_2}{2\pi d}$$

$$= \frac{(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A})(4.0\ \text{A})(4.0\ \text{A})}{2\pi(0.050\ \text{m})}$$

$$\frac{F_2}{l} = 6.4 \times 10^{-5}\ \text{N/m}$$

The magnitude of the force was 6.4×10^{-5} N.

REF: C   OBJ: 8.4   LOC: EG1.07